Driving a Crop Growth Simulation Using Canopy Spectral Reflectance Estimates of Leaf Area Index

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Introduction

Great efforts have been taken to programmatically synthesize current agronomic knowledge into computer simulation models. However, the applicability of these models has been limited, because many input parameters must be specified and model calibration against field measurements is often necessary to insure adequate model performance. Field data collection is typically a very expensive, labor intensive and time-consuming endeavor.

Remote sensing has been proposed as a relatively quick, easy, and inexpensive source of information that relates well with key model state variables, such as green leaf area index (GLAI). Several data assimilation strategies have been developed for merging remote sensing with model simulations. The 'updating' strategy simply overwrites the model state variable with the measured value on the measurement date. The 'forcing' strategy overwrites the model state variables with the measurement on a daily time-step, relying on linear interpolation to derive the values between measurement dates.

Our objectives were to 1) develop these techniques for assimilating remote sensing estimates of GLAI into the CERES-Wheat crop model and to 2) evaluate the ability of the assimilation strategy to improve simulations of crop yield and evapotranspiration using data from a field study in central Arizona.

Field Experiments

Irrigation scheduling experiments over 32 plots were conducted in wheat during the winter of 2003-2004 and 2004-2005 at Maricopa, Ariz. (Hunsaker et al., 2007). Main treatments included two irrigation scheduling methods, one using standard FAO-56 procedures and the other using real-time remote sensing-based estimates of crop coefficients. To produce variability in crop growth characteristics, sub-treatments included two nitrogen application rates and three population densities. These experiments provided much data for the current investigation, including:

- •Soil moisture – twice weekly
  - •Neutron probe at 20 cm increments
  - •Water balance estimate of ET
- •Agronomic
  - •Weekly crop development
  - •Bi-weekly biomass samples
  - •Crop yield
- •Meteorological – continuous monitoring
- •Canopy reflectance – twice weekly
  - •Exotech four-band radiometer
  - •Used to compute NDVI

Estimating GLAI from NDVI

Choudhury's method, as implemented by French et al. (2007), was used to compute GLAI from NDVI. Fractional vegetation cover is computed from NDVI using:

$$f = 1 - \left(\frac{\mathrm{NDVI}_{\max} - \mathrm{NDVI}}{\mathrm{NDVI}_{\max} - \mathrm{NDVI}_{\min}} \right)^{1/\xi}$$

where NDVI measurements are rescaled according to the bare soil index, $\mathrm{NDVI}_{\max}$, and the full vegetation cover index, $\mathrm{NDVI}_{\min}$. The parameter, ξ, is a function of canopy leaf angle distribution. The GLAI is then computed from f according to:

$$\mathrm{GLAI} = \left(\frac{\ln(1-f)}{-\beta} \right)$$

where β is a second function of leaf angle distribution. Values for ξ and β were specified as 1.85 and 0.716, based on results of French.

Data Assimilation Strategy

Assimilation of remotely sensed GLAI estimates into the CERES-Wheat model was expected to influence both the water balance simulation and the crop growth simulation, since the GLAI state variable is involved in the computation of both evapotranspiration and the fraction of photosynthetically active radiation intercepted by the plant canopy. CERES-Wheat was reprogrammed to accept GLAI inputs and to adjust the plant leaf area (PLA) and the GLAI state variables based on the remotely sensed GLAI observations. Data assimilation by 'updating' and 'forcing' was then tested using different soil texture inputs to demonstrate the ability of the assimilation strategy to improve model simulations of crop yield and evapotranspiration when soil properties were uncertain.

Results

Results demonstrated that the 'updating' and 'forcing' data assimilation strategies could improve CERES-Wheat simulations of crop yield and ET as long as the soil texture inputs were similar to actual soil texture at the site (OBS), which was best classified as a sandy loam. If soil parameters for loam (L), loamy sand (LS), or sandy loam (SL) were used, crop yield and ET simulations were consistently improved using the data assimilation. This result was less consistent when using sandy clay loam (SCL) and silty loam (SiL) soil inputs, where the yield and ET simulations were sometimes improved, but not always. Use of soil input parameters for any other soil type (data not shown), which were more dissimilar to the actual soil texture, did not result in an improvement. Proper specification of soil parameters is required before data assimilation techniques can further improve the model.

Results

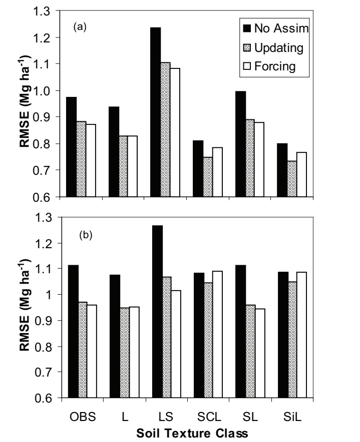

Figure 1. Root mean squared error between measured and simulated yield for the a) 2003-2004 and b) 2004-2005 growing seasons under no data assimilation and data assimilation by 'updating' and 'forcing' using different soil inputs.

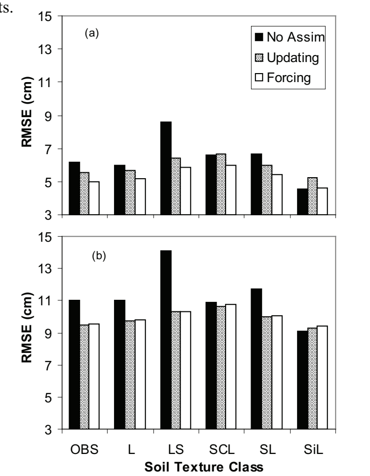

Figure 2. Root mean squared error between measured and simulated evapotranspiration for the a) 2003-2004 and b) 2004-2005 growing seasons under no data assimilation and data assimilation by 'updating' and 'forcing' using different soil inputs.

Conclusions

As long as the CERES-Wheat soil input parameters are reasonably specified, assimilation of remotely sensed estimates of GLAI into the model can improve simulations of yield and evapotranspiration.

References

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